MULTIMEDIA **IIIᵔ I** UNIVERSITY

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EME2146 – APPLIED THERMODYNAMICS
(ME)

10 MARCH 2020
02.30 p.m. - 04.30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of six pages (including the cover page) with four questions and an Appendix.

2. Answer ALL four questions.

3. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].

4. Write all your answers in the answer booklet provided.

5. Property-tables booklet is provided for your reference.

Question 1

Propane gas (C_3H_8) is delivered at a constant rate of 88 g/s. It is mixed with 200 % excess air (dry air) at the same temperature of 298 K. The mixture is combusted completely at the constant pressure of 100 kPa. The product gases of combustion exit the chamber at 500 K. Assume ideal gas for the mixtures of products and reactants where the universal gas constant, $R = 8.314$ J/mol·K.

Substance	N_2	O_2	CO_2	H_2O	C_3H_8
Molecular weight (kg/kmol)	28	32	44	18	44

The dry air composition: nitrogen to oxygen ratio by mole = 3.76.

a.   Write the stoichiometric combustion equation.

[3 marks]

b.   Write the combustion equation with 200% excess air.

[3 marks]

c.   Calculate the air-fuel ratio.

[3 marks]

d.   Find the enthalpy of formation for C_3H_8, CO_2, and H_2O at 298 K and 100 kPa from the property table.

[3 marks]

e.   Determine the rate of heat transfer from the combustion in kW.

[8 marks]

f.   Calculate the amount of water vapor condensed after 10 minutes if the product gaseous are cooled to 298 K at 100 kPa. The saturated water vapor pressure at 298 K is 3.1698 kPa.

[5 marks]

Continued...

Question 2

A 2.0 liter, single-cylinder compression-ignition internal combustion engine is assumed to operate on an ideal Diesel cycle. Air and fuel are mixed and enter the engine at the atmospheric conditions, 100 kPa and 300 K before it is compressed isentropically. The compression ratio and cut-off ratio are 20 and 2 respectively. Assume idea gas of the air-fuel mixture, the constant volume specific heat, $c_v = 710$ J/kg·K and the specific heat ratio, $\gamma = 1.4$. The isentropic relation: $Tv^{\gamma-1} = $ constant, $T^\gamma p^{1-\gamma} = $ constant.

a.   Sketch and label the $T - s$ and $p - v$ diagrams of the cycle.

[4 marks]

b.   Calculate the mass of the air and fuel mixtures.

[3 marks]

c.   Find the temperature after compression.

[2 marks]

d.   Find the highest temperature of the cycle.

[2 marks]

e.   Find the exit temperature of the exhaust gases.

[2 marks]

f.   Determine the amount of heat addition per cycle.

[3 marks]

g.   Determine the amount of heat rejection per cycle.

[3 marks]

h.   Determine the amount of net work output per cycle.

[2 marks]

i.   Calculate the thermal efficiency of the cycle.

[2 marks]

j.   If the Diesel engine is modified by allowing the pressure to build up during the first phase of heat addition, while the compression ratio and cut-off ratio remain intact. Sketch the $p - v$ diagrams of the dual cycle.

[2 marks]

Continued...

Question 3

A cylindrical chamber contains 2 mol of gaseous substance. Heats are transferred to the cylindrical chamber at constant temperature from a source and sink while the piston is moved in such a way that the temperature of the chamber, T_{in} = 600 K, is maintained constant throughout the expansion process. During the expansion process, the piston moves from its initial position (enclosed volume, V_1) to the final position, (enclosed volume, $V_2 = 5V_1$) while the amount of heat transferred, Q_{in} = 6 kJ. Assume ideal gas and constant specific heat, γ = 1.4, for the gaseous substance where the universal gas constant, R = 8.314 J/mol·K, and ambient temperature, T_0 = 300 K.

a.   Determine the maximum work output.

[7 marks]

b.   Find the irreversibility of the process.

[3 marks]

c.   If the expansion process is carried out by transferring the same amount of heat, but the piston is held at its initial position. Then, it is expended to final position adiabatically. What is the irreversibility of the process?

[15 marks]

Continued...

Question 4

a.   Starting from the First Law of Thermodynamics, derive the specific heat ratio and express it in term of isothermal and isentropic compressibilities.

[5 marks]

Consider the isothermal expansion process of the reversible Ericsson cycle. A gaseous pure substance flows through a non-adiabatic turbine at the constant rate of $\dot{n} = 2$ mol/s, as shown in Figure Q4. The gas enters the turbine at 500 kPa and 600 K and exists at atmospheric pressure, 100 kPa. Heat transfer is allowed during the expansion process and temperature is maintained constant through the turbine.
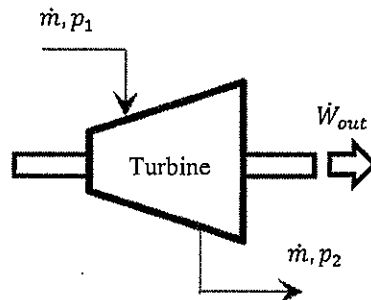
Figure Q4

Within the operating condition of the turbine, the gas is found to have the expansivity, isentropic compressibility, and specific heat ratio as:

$$\alpha_p = \frac{1}{T - b} \; ; \; \beta_s = \frac{1}{\gamma p} \; ; \; \gamma = 1.4$$

where $b = 100$ K, is the empirical constant. At high temperatures, $T \gg b$, the gas behaves like an ideal gas. The universal gas constant, $R = 8.314$ J/mol·K.

b.   Determine the equation of state of the substance.

[8 marks]

c.   Find the rate of heat transfer of the turbine.

[6 marks]

d.   Calculate the power output of the turbine.

[6 marks]

Continued...

APPENDIX

A1. Clapeyron and Maxwell Relations:

$$\frac{dp_{sat}}{dT} = \frac{s_{fg}}{v_{fg}} = \frac{h_{fg}}{Tv_{fg}} \; ; \; \left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v \; ; \; \left(\frac{\partial T}{\partial p}\right)_s = \left(\frac{\partial v}{\partial s}\right)_p \; ; \; \left(\frac{\partial v}{\partial T}\right)_p = -\left(\frac{\partial s}{\partial p}\right)_T \; ; \; \left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$$

A2. Change of internal energy, enthalpy, and entropy:

$$u_2 - u_1 = \int_{T_1}^{T_2} c_v dT + \int_{v_1}^{v_2} \left[T\left(\frac{\partial p}{\partial T}\right)_v - p \right] dv \; ; \; h_2 - h_1 = \int_{T_1}^{T_2} c_p dT + \int_{p_1}^{p_2} \left[v - T\left(\frac{\partial v}{\partial T}\right)_p \right] dp$$

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{c_v}{T} dT + \int_{v_1}^{v_2} \left(\frac{\partial p}{\partial T}\right)_v dv = \int_{T_1}^{T_2} \frac{c_p}{T} dT - \int_{p_1}^{p_2} \left(\frac{\partial v}{\partial T}\right)_p dp$$

A3. Enthalpy, entropy and internal energy of departure:

$$\frac{(h^* - h)_T}{RT_c} = \int_0^{p_r} \left[T_r^{\,2} \left(\frac{\partial Z}{\partial T_r}\right)_p \right] \frac{dp_r}{p_r}$$

$$\frac{(s^* - s)_T}{R} = \int_0^{p_r} \left[Z - 1 + T_r \left(\frac{\partial Z}{\partial T_r}\right)_p \right] \frac{dp_r}{p_r}$$

$$\frac{(u^* - u)_T}{RT_c} = \frac{(h^* - h)_T}{RT_c} + T_r(Z - 1)$$

A4. Relation between relative humidity, absolute humidity, dry-bulb and wet-bulb temperature:

$$\phi = \frac{\omega}{\omega + 0.622}\left(\frac{p_T}{p_{v*}}\right) \; ; \; \omega = \frac{0.62\phi p_{v*}}{p_T - \phi p_{v*}} \; ; \; \omega = \frac{\left(\frac{0.622}{p_T/p_{v*@Twb} - 1}\right) h_{fg@Twb} - c_{pa}(T_{db} - T_{wb})}{h_{fg@Twb} + h_{f@Tdb} - h_{f@Twb}}$$

A5. Isentropic relations of ideal gas:

$$p = \rho RT \; ; \; c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right) = 0 \; ; \; \frac{p}{\rho^\gamma} = \text{const.} \; ; \; \frac{T}{T_0} = \left(\frac{p}{p_0}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{\rho}{\rho_0}\right)^{\gamma-1}$$

A6. General relations for specific heats:

$$c_p - c_v = \frac{Tv\alpha_p^{\,2}}{\beta_T} \; ; \; \gamma = \frac{c_p}{c_v} = \frac{\beta_T}{\beta_s} \; ; \; c_p = \frac{\gamma Tv\alpha_p^{\,2}}{(\gamma - 1)\beta_T} \; ; \; c_v = \frac{Tv\alpha_p^{\,2}}{(\gamma - 1)\beta_T} \; ; \; c_p - c_v = R \text{ (ideal gas)}$$

A7. Some useful calculus relations:

Integration by parts:
$$\int \spadesuit(\blacklozenge)\ (\blacklozenge)\, d\blacklozenge = \spadesuit(\blacklozenge) \int (\blacklozenge)\, d\blacklozenge - \int \left[\left(\int (\blacklozenge)\, d\blacklozenge \right) \spadesuit'(\blacklozenge) \right] d\blacklozenge$$

Integration of quotient:
$$\int \frac{'(\blacklozenge)}{(\blacklozenge)} d\blacklozenge = \ln[\ (\blacklozenge)]$$

Differentiation of product
$$(\spadesuit(\blacklozenge)\ (\blacklozenge))' = \spadesuit'(\blacklozenge)\ (\blacklozenge) + \spadesuit(\blacklozenge)\ '(\blacklozenge)$$

Differentiation of quotient:
$$\left(\frac{\spadesuit(\blacklozenge)}{(\blacklozenge)}\right)' = \frac{\spadesuit'(\blacklozenge)\ (\blacklozenge) - \spadesuit(\blacklozenge)\ '(\blacklozenge)}{[\ (\blacklozenge)]^2}$$

Cyclic relation:
$$\left(\frac{\partial \spadesuit}{\partial}\right)_{\blacklozenge} \left(\frac{\partial}{\partial \blacklozenge}\right)_{\spadesuit} \left(\frac{\partial \blacklozenge}{\partial \spadesuit}\right) = -1$$

End of Paper